CLIMATE-FIRE RELATIONSHIPS IN THE SOUTHERN APPALACHIAN MOUNTAINS

A Senior Scholars Thesis

by

RALPH C. BAKER

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2009

Major: Geography

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Approved by:

Research Advisor: Charles W. Lafon
Associate Dean for Undergraduate Research: Robert C. Webb

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ABSTRACT

Climate-fire Relationships in the Southern Appalachian Mountains. (April 2009)

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This study is meant to explain the fire regime of the southern Appalachian Mountain Range of the southeastern United States by analyzing spatial statistics and climate-fire relationships. The spatial statistics were created by obtaining then computing data from the National Interagency Fire Management Integrated Database (NIFMID), which has covered fires in national forests since approximately 1970, and the Continuous Inventory of Stand Condition (CISC) database. Once the data was computed it was entered into GIS software where it was spatially analyzed. Climatic teleconnections relate the anomalies in the atmosphere across the globe; they have been theorized to affect weather. The numeric representations of selected teleconnections were collected from the National Oceanic and Atmospheric Administration (NOAA) and correlated to fire history data from the NIFMID dataset. The correlations were analyzed to determine which teleconnections and at what time period affect fires in the region. Annual statistics about the fire history were correlated to the teleconnections of each of the

previous 24 months. The study found that the fire regime can be described as consisting of three distinct fire seasons: spring anthropogenic, summer lightning and fall anthropogenic. Spring and fall are prime fire seasons because of the combined climate conditions of it being dry and windy. Summer conditions are not as favorable for fire, but that is primarily when lightning occurs. PDSI was found to strongly correlate (above the .001 significance level) to fire as would be expected in a humid climate. Anthropogenic fires were shown to correlate significantly (above the .05 significance level) to all teleconnections for at least one of the 24 months. Lightning fires did so for some of the teleconnections. After looking at the spatial statistics of fire in the study area, the general patterns observed were that fire was most impactful in north-western Georgia, eastern Tennessee and northwestern North Carolina and that fires in other areas, though plentiful, were small.

ACKNOWLEDGMENTS

I would like to thank Dr. Charles Lafon and Will Flatley for allowing me to do field research with them in Great Smokey Mountains National Park, and then allowing me to continue working on the project once we returned. Dr. Lafon has helped me immensely by being my advisor throughout the writing of this thesis by giving me advice and providing resources. Will Flatley guided me through the process of doing the research, and answering any questions I had.

I would also like to thank the Undergraduate Research Scholars program for allowing me to not only partake in research at the undergraduate level, but also providing the forum to write a thesis. They provided many resources for everyone that participated in the program without which this whole undertaking would have been much more difficult.

NOMENCLATURE

AMO	Atlantic Multidecadal Oscillation
C	Celsius
CPC	Climate Prediction Center
ENSO	El Nino/Southern Oscillation
EP/NP	East Pacific/North Pacific
NAO	North Atlantic Oscillation
NCDC	National Climatic Data Center
NIFMID	National Interagency Fire Management Integrated Database
NLDN	National Lightning Detection Network
PDSI	Palmer Drought Severity Index
PNA	Pacific/North American
SST	Sea Surface Temperature

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CHAPTER I

INTRODUCTION

In recent years, there has been an emphasis put on restoring the pre-settlement fire regime of low intensity fires in the southern Appalachian Mountains (Brose, *et al.*, 2001). In order to do this the current fire regime needs to be understood. Two primary factors in the fire regime are spatial patterns and climatic influences. In the adjacent central Appalachian Mountains, the basic spatial pattern was found to be fire influence decreased from east to west and from low to high elevations (Lafon & Grissino-Mayer, 2007). Somewhat similar patterns are expected in the southern Appalachians; though tropical moisture from the Gulf of Mexico may affect the southern sections' fire regimes. Climatic influences, measured by teleconnection indices, have been shown to influence the precipitation patterns of the south-eastern United States (Henderson & Robinson, 1994 & Yin, 1994). A study in Mississippi found that multiple teleconnections could be correlated to fire within the state; it also found that teleconnections could be used as a predictor of fire on a multi-month time scale (Dixon *et al.*, 2008). The teleconnections that affect fire in the southern Appalachian Mountains will be determined.

This thesis follows the style of the *Journal of Biogeography*.

Overview of spatial patterns of fire

The spatial patterns of fire are affected by many complicated factors some of which are regional climate, human impacts and topography. The central Appalachian Mountains are divided into three physiographic regions; a study of the spatial pattern of fire there concluded that the fire regime differed significantly between the regions due primarily to variations in climate and topography (Lafon & Grissino-Mayer, 2007).

Overview of climatic influences

Fires, especially large ones, occur primarily during drought conditions. The PDSI value for a location is used to determine the severity of a drought. The more negative the PDSI value is the drier and more fire prone the location will be. Moisture and temperatures, which are factors in controlling PDSI, are controlled by the climate which can be explained by studying climatic teleconnections. Teleconnections link the atmosphere of different locations; to quantify them teleconnection indices have been developed.

Probably the best known teleconnection index is the ENSO which is a measure of SST temperature anomalies in the eastern equatorial Pacific. A positive anomaly results in El Nino conditions while a negative anomaly results in La Nina conditions. The warming associated with El Nino triggers changes in the atmosphere far from the eastern, equatorial Pacific where the anomaly occurs (Sterl *et al.*, 2007). For the Southeastern

US a positive ENSO (El Nino) will typically result in cool, moist conditions (Ropelewski & Halpert, 1986).

There are many other teleconnections which have been shown to or could affect the region's climate. The NAO index is a measure of the pressure difference between the Azores High and the Icelandic Low (Dixon *et al.,* 2008; Yin, 1994).   According to Yin a positive NAO will tend to result in mild, moist conditions for the eastern US (1994). The PNA index indicates the amplitude of the ridge/trough pattern across the north Pacific and North America. A positive value results in a strong trough across the eastern US with cool temperatures. Negative PNA values result in a more zonal flow across the north Pacific and North America (Dixon *et al.,* 2008; Yin, 1994). The AMO index reflects multi-decadal changes in SSTs over the North Atlantic Ocean; during its warm phase temperatures tend to be warmer and drought is more prevalent for most of the US. The EP/NP index reflects height anomalies in the eastern North Pacific, central North Pacific and the eastern US; the positive phase tends to result in cool, moist conditions in the eastern US. Several teleconnections will be analyzed to determine their affect on the fire regime of the southern Appalachian Mountains.

Inquiries

This study aims to answer the following questions and by doing so hopefully explain the fire regime of the southern Appalachian Mountains:

(1) Is fire in the region related to PDSI? If so, which months relate most closely? Are wet conditions required to build up fuel for fires in subsequent years?

(2) Is fire in the region related to teleconnections? If so, which ones and which months relate most closely to the teleconnection being observed?

(3) Are there spatial patterns of burning at the level of National Forest ranger districts? If so, can this pattern be explained by climate, human impacts and/or topography?

CHAPTER II

METHODS

Study area

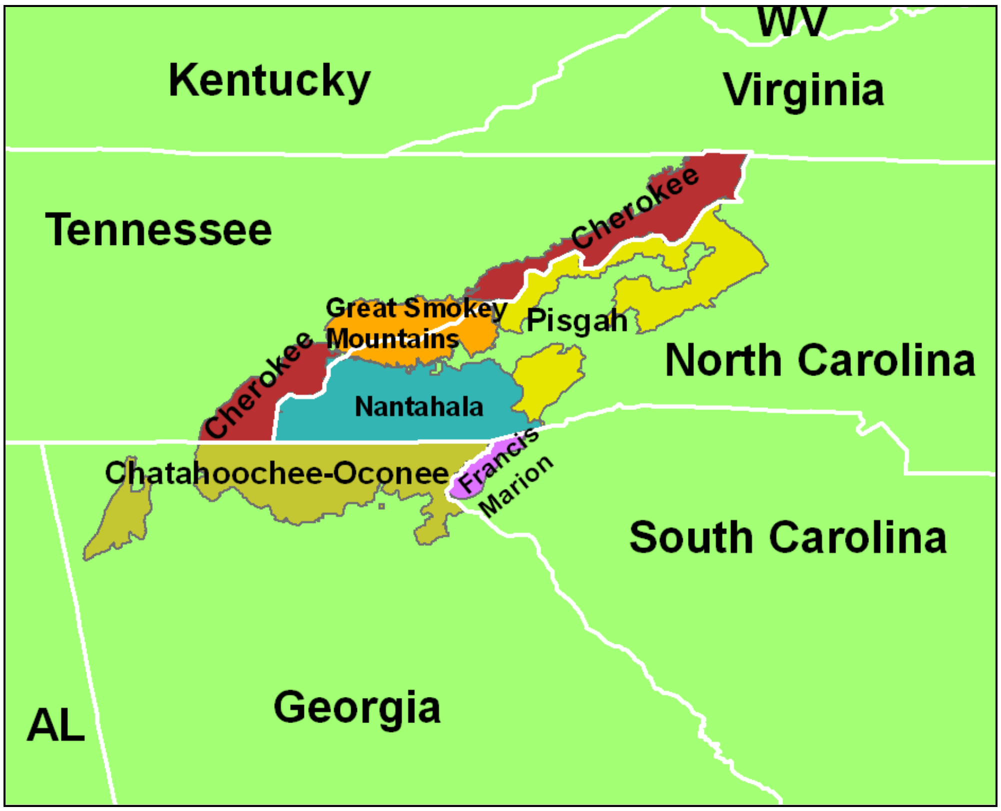

Figure 1 Map of national forests and parks included in the study. Only federally owned land within these areas were selected for analysis.

The southern Appalachians stretch from northern Georgia and far western South Carolina north along the Tennessee/North Carolina border as shown in Fig. 1. The region is roughly the southern half of Bailey's Central Appalachian Broadleaf Forest--Coniferous Forest--Meadow Province; the region is mountainous with elevations ranging from 300ft to 6,684 ft at Mt. Mitchell in North Carolina. Along with this large variance in elevation comes much vertical zonation of the vegetation. Mixed oak-pine forests can be found at low elevations with Appalachian oak forests, northeastern hardwood forests and spruce-fir forests found in respective order as elevation increases. Mixed mesophytic forests can be found in the narrow valleys (coves) (Bailey, 1978).

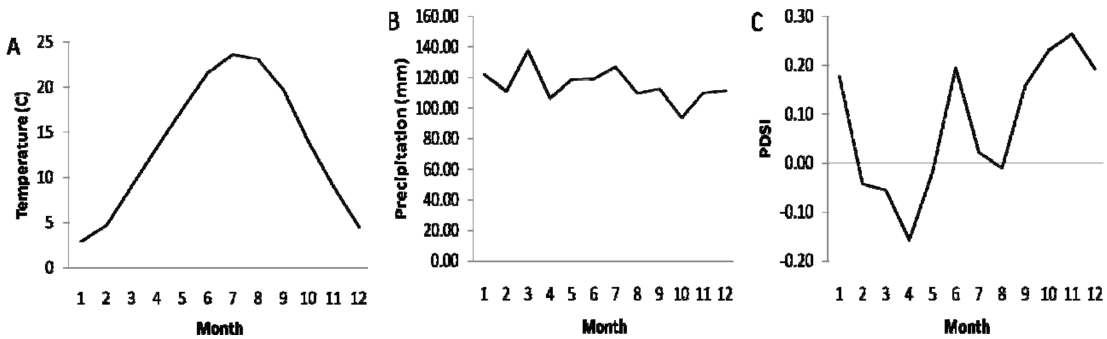

Figure 2 Average precipitation (A), temperature (B) and PDSI (C) for the study area (Divisional Data Select, 2008).

The study area is characterized by fairly consistent precipitation and large temperature variability (Fig. 2). Fig. 2 shows that low PDSI values, which measure the severity of drought, are more prevalent during the spring than any other season while winter months and late spring/early summer are characterized by higher PDSI values.

Climate/fire relationship analysis

Data on fires within the study area between 1970 and 2007 was collected from the NIFMID website (Fire and Weather Data, 2009). The annual statistics on the total number of fires, total hectares burned and average hectares burned per fire were all calculated for the entire study for both lightning and anthropogenic fires. The collected fire data was correlated to multiple teleconnections (ENSO, NAO, AMO, PNA and

EP/NP) which were obtained from the CPC for the years 1970 through 2007. The area burned by lightning and anthropogenic fires for each month from 1971 to 2007 was correlated to the teleconnection indices of each of the previous 24 months; this was done for each of the teleconnection indices. When a significant correlation was found it could be said with relative certainty that the area burned by lightning and anthropogenic fires of that month was related to the teleconnection indices of the related month.

The annual statistics on the total number of fires, total hectares burned and average hectares burned per fire for the years 1971 through 2007 were correlated to the monthly PDSI of the previous 24 months; these calculations were done on the both lightning and anthropogenic fires. Additionally, anthropogenic fires were separated by whether they occurred during the spring or fall half of the year, and the same calculations were done.

Spatial/fire analysis

NIFMID data on all fires occurring within federal lands through 2007 was obtained; the data was separated by National Forest ranger district and by lightning or anthropogenic fire. The number of fires, total area burned and GIS calculated area for both fire types were calculated for each ranger district. GIS shapefiles of federally owned lands within the study area were created. The shapefiles were attributed with the six fire data fields specified above. Six maps were created; these were a lightning and anthropogenic version of percent area burned, area burned per fire and number of fires per 1 ha. The percent area burned maps were created by dividing the area burned by total GIS calculated area. The area burned per fire was calculated by dividing the area burned by the number of fires. The number of fires per 1000 ha maps were created by dividing the number of fires by the GIS area and multiplying this value by 1000.

CHAPTER III

RESULTS

Explanation of fire in the region

Lightning caused fires and anthropogenic caused fires show different patterns spatially and in their inter-annual cycles as seen in Fig. 3. Lightning fires have a summer peak in area burned with the maximum occurring in June within which 104.85 ha burned on average each year from 1970 until 2007. The inter-annual pattern of anthropogenic fires is bimodal with summer and fall peaks. In the spring, there is a relative maximum average area burned in the month of April when 763.92 ha burn on average; the relative maximum in the fall season occurs in November when 757.05 ha burn on average.

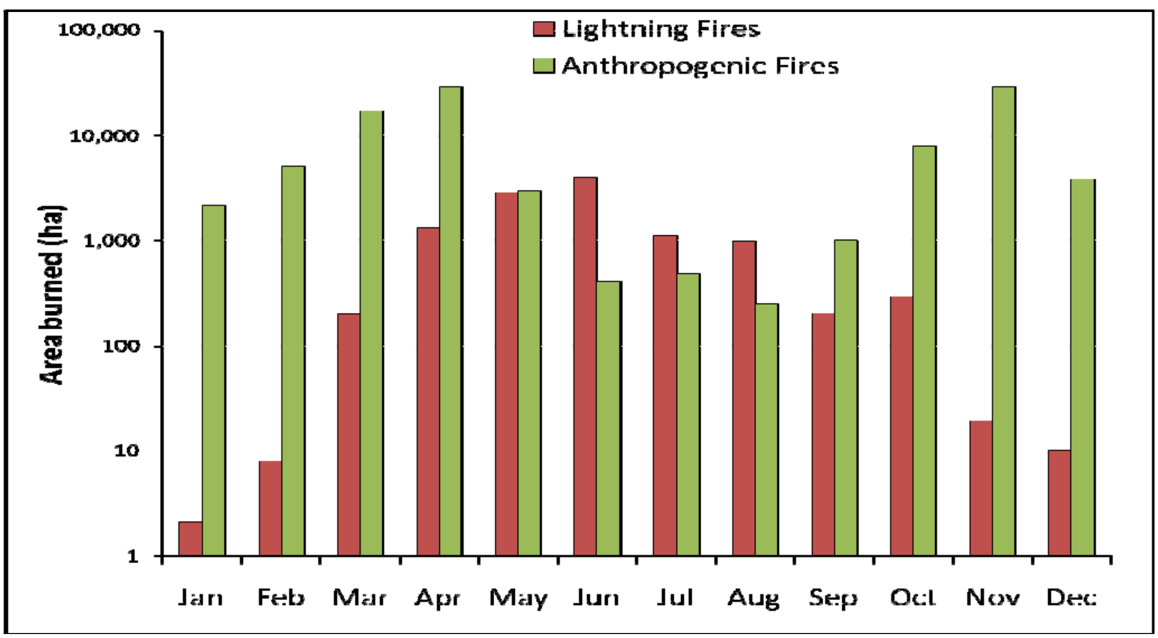

Figure 3 Area burned by lightning ignited fires and anthropogenic caused fires in each month between the years of 1970 and 2007.

PDSI is strongly related to area burned for all fire types (Fig. 4). Spring anthropogenic fires are most closely related to the spring months of the current year, the value is stronger than the .001 significance level from February through July. While the fall fires are more closely related to PDSI of the current fall; it crosses the .001 significance level during the current December, and the .05 level is surpassed from the current October through December. The .05 significance level is surpassed from the current March to the end of the year for lightning fires, and the .001 level is surpassed in the current September.

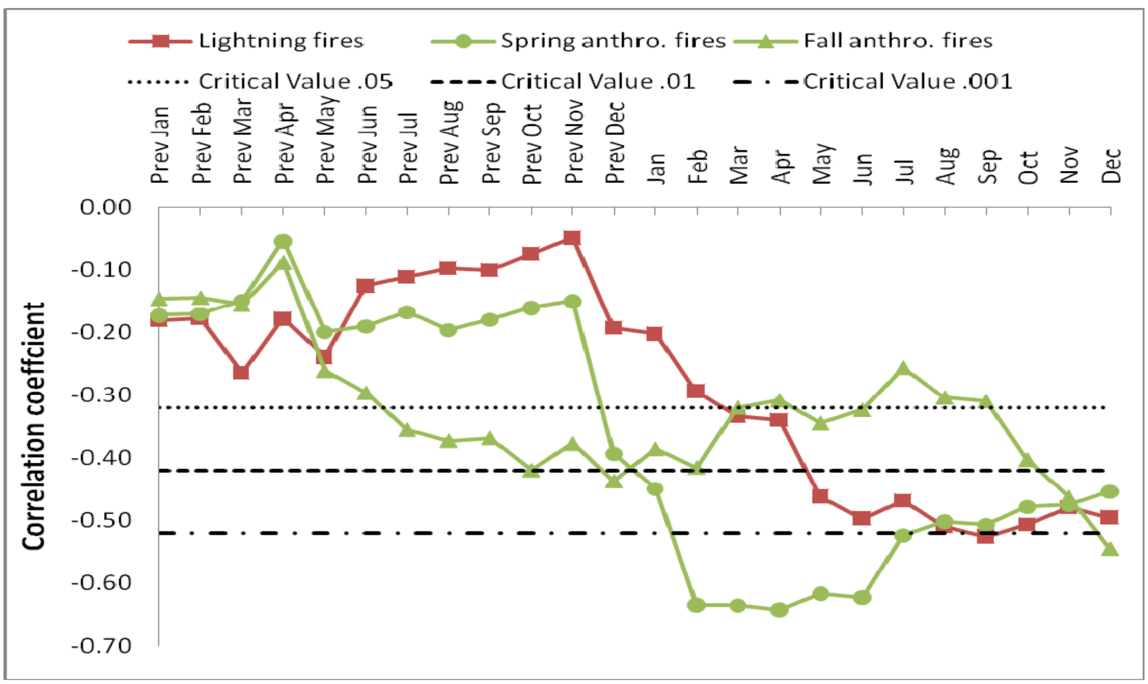

Figure 4 Correlation of lightning, spring anthropogenic and fall anthropogenic area burned annually between 1970 and 2007 to the monthly PDSI of the current year and one year prior to the current year.

Relationship to teleconnections

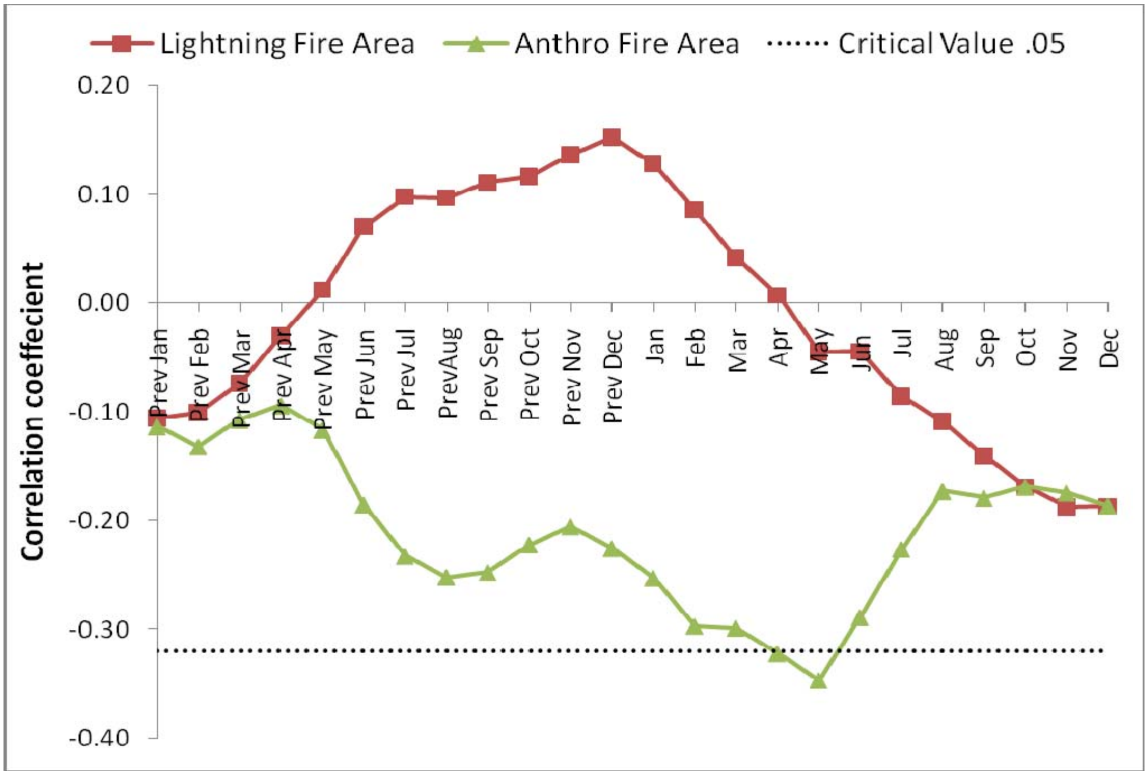

Figure 5 24 month correlation of ENSO to the annual area burned by lightning and anthropogenic fires.

The correlation pattern that is produced by ENSO-area burned correlation is somewhat smooth (Fig. 5). The positive correlation of lightning fires' area burned to ENSO is strongest during the previous December when it was .15, and the strongest negative correlation is -.19 occurring in November and December of the current year neither of which is statistically significant. The area burned by anthropogenic fires' correlation to ENSO is always negative with the strongest correlations occurring in the previous and current summers. The anthropogenic correlation surpasses the .05 significance level during the current April and May.

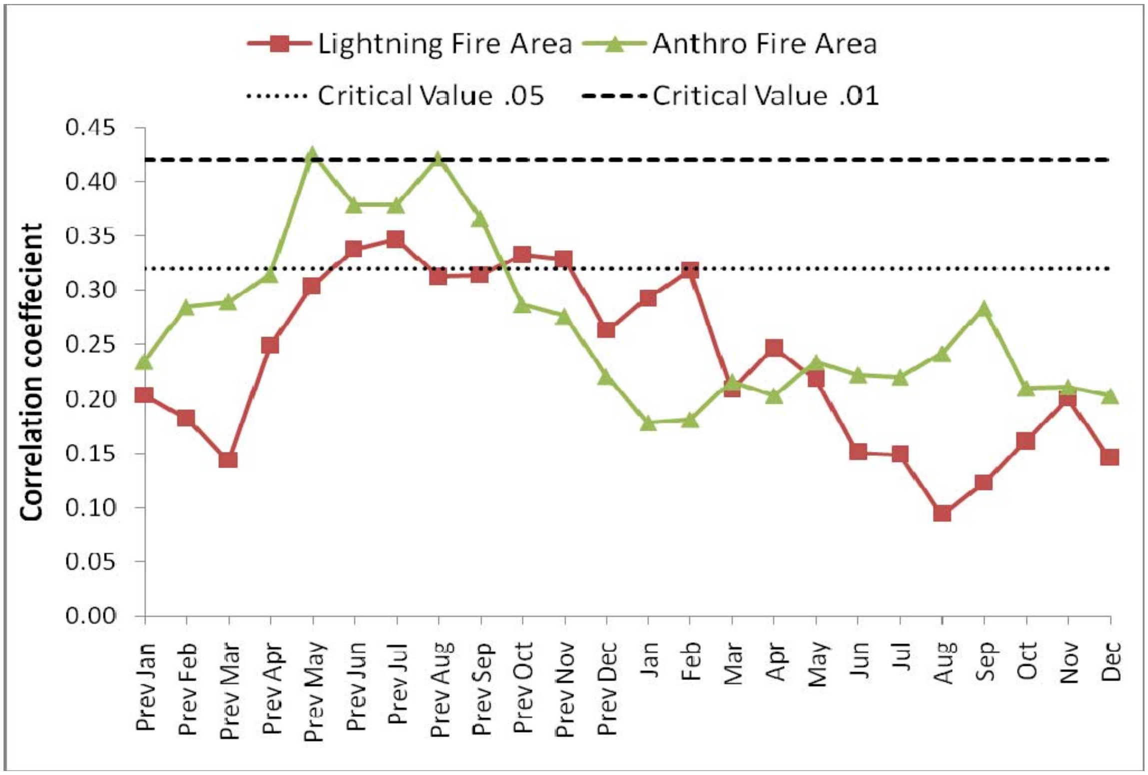

Figure 6 24 month correlation of AMO to the annual area burned by lightning and anthropogenic fires.

The correlation pattern of AMO to the total area burned annually by lightning and anthropogenic fires produced a somewhat smooth pattern of correlation change (Fig. 6). For both fire types the strongest correlations occurred during the previous year's summer when both types' correlations surpassed the .05 significance level. Anthropogenic fires' strongest correlation occurs in the previous year's May and August when it reaches the .01 level. Lightning fires' correlation surpasses the .05 significance level during the previous year's June, July, October and November.

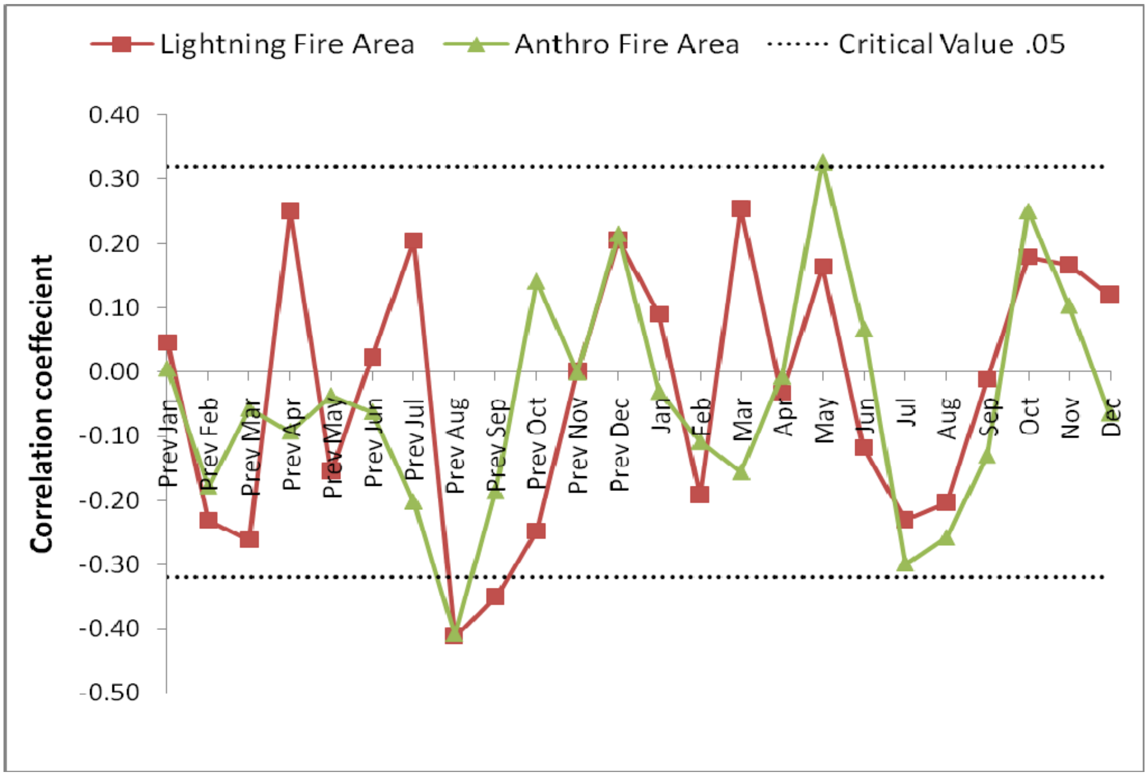

Figure 7 24 month correlation of NAO to the annual area burned by lightning and anthropogenic fires.

For NAO the correlation patterns of both fire types changes in a way that seems to be sporadic (Fig. 7). For anthropogenic fires the .05 significance is reached during the previous August and in the current year’s May. The .05 level is surpassed during the previous August and September for lightning fires.

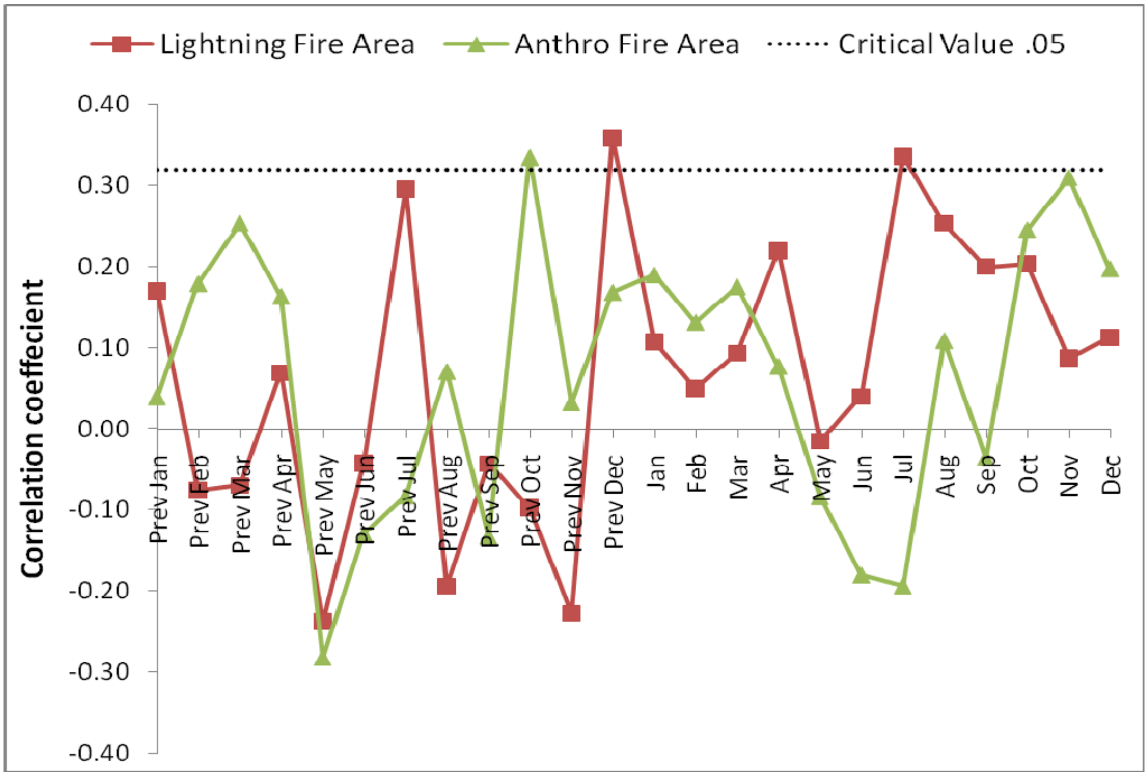

Figure 8 24 month correlation of PNA to the annual area burned by lightning and anthropogenic fires.

For PNA the monthly variation in correlation changes in what seems to be a sporadic way (Fig. 8). Anthropogenic fires cross the .05 significance level in the previous October, and nearly do so in the current year's November. Lightning fires are significant at the .05 level during the previous year's December and in the current year's July.

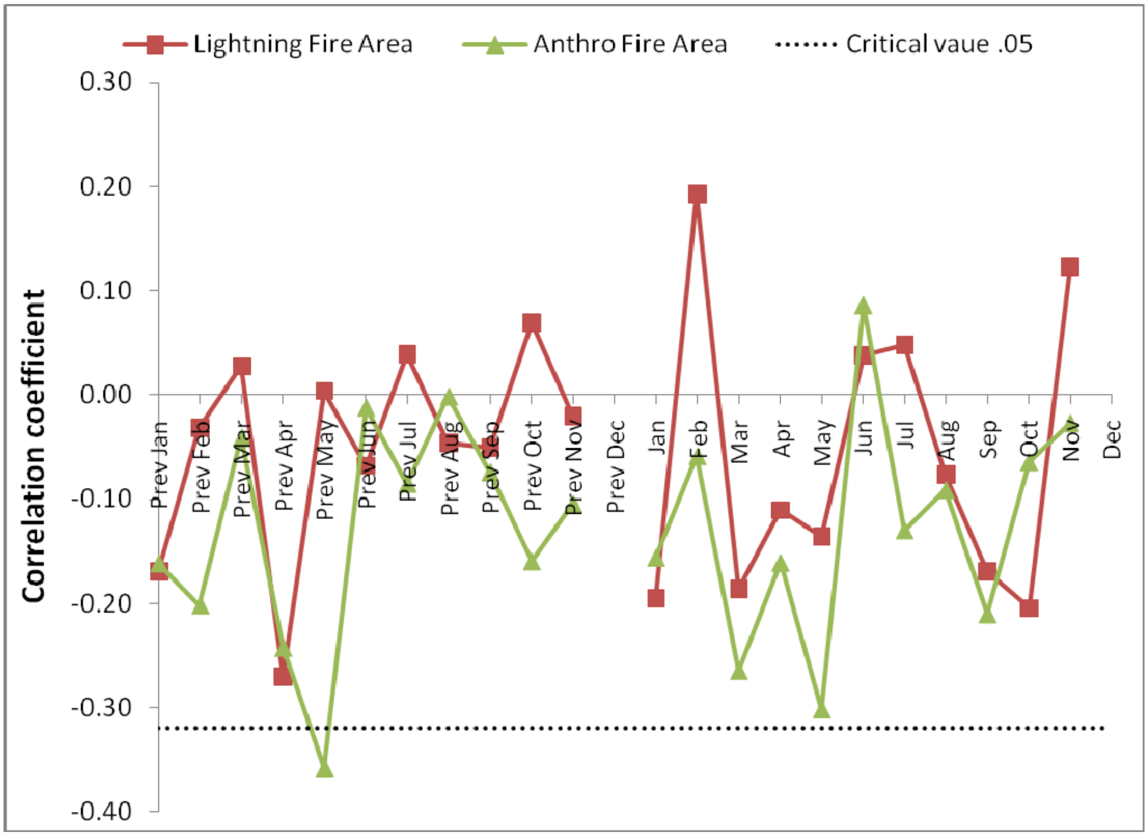

Figure 9 24 month correlation of EP/NP to the annual area burned by lightning and anthropogenic fires.

EP/NP also has a pattern that seems to be sporadic and it becomes significant during one month (Fig. 9). The values for December were null so both Decembers were excluded. The .05 significance level is crossed during the previous year's May for anthropogenic fires; the next two strongest correlation months are the current year's March and May. The two strongest correlations of lightning fires occur during the current year's February and November.

Spatial results

The fire density in the west and north tended to be higher with densities as high as 33% burned in the Nolichucky Ranger District (in eastern Tennessee) and as low as 2% burned in the Cohutta Ranger District (in northern Georgia). The range in average fire size seems to be found throughout the region. Throughout the study area the average fire size was 20.4 ha. While, the average fire size in Great Smokey Mountains National Park was 35.8 ha which was the maximum, and in the Hiwassee Ranger District the average fire size was 2.4 ha which was the minimum (Fig. 10).

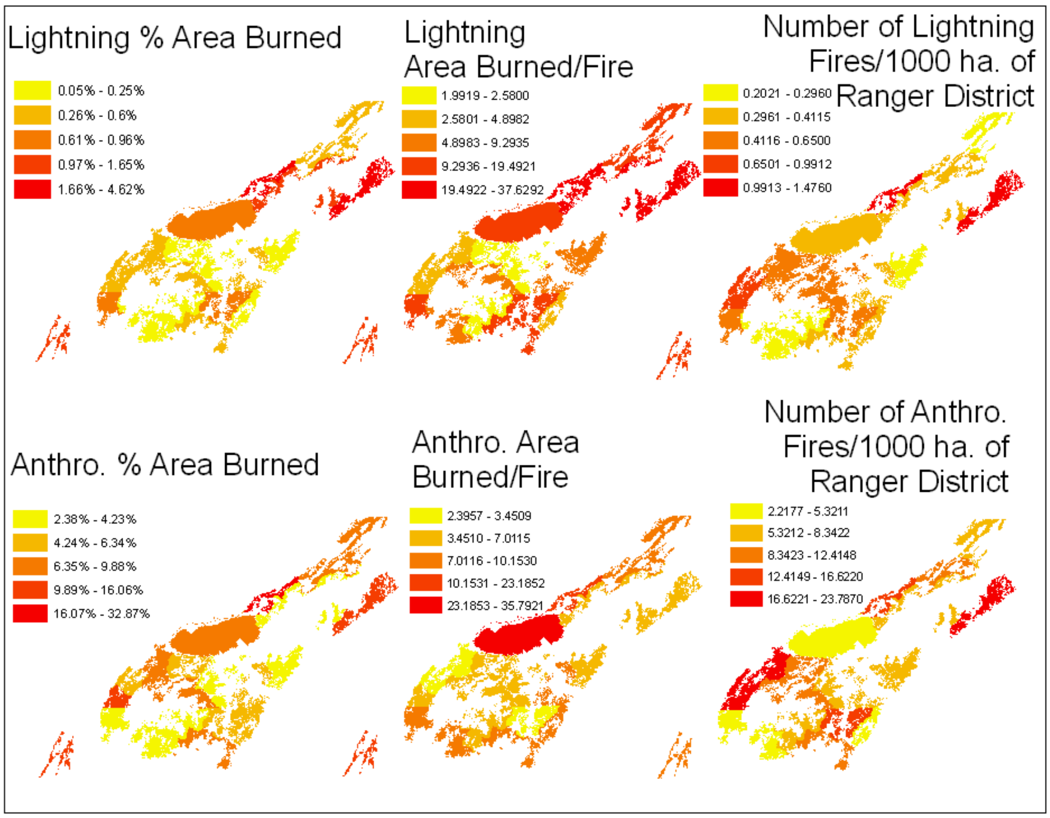

Figure 10 Maps of the spatial statistics of fire within federal lands of the study area. The lightning and anthropogenic % area burned maps represent the area burned by fire type divided by total area of the given ranger district. The lightning and anthropogenic area burned/fire maps represent the average fire size of each type of fire within the ranger district. The lightning and anthropogenic fires/ 1000 ha of ranger district maps represent the number of fires that occur per 1000ha of the given ranger district.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

The basic fire regime consists of three fire seasons being: spring anthropogenic, summer lightning and fall anthropogenic; this pattern was also observed in the central Appalachian Mountains (Lafon, *et al*., 2005). Both anthropogenic fire seasons coincide with the driest times of the year according to the PDSI, and spring and fall are warm months. In the adjacent central Appalachian Mountains wind speeds were high and humidity was low during the spring and fall both of which are favorable for fire; the same would be expected in the southern Appalachian Mountains. Lightning fires occur in the summer which does not generally have as favorable conditions with high humidity and low wind speeds (Lafon, *et al.*, 2005). Though conditions are not perfect for fire in the summer that is when the majority of lightning is believed to occur within the study area.

PDSI seems to be a primary controller of fire in the study area with the statistical significances of the correlations to annual area burned of all fire types being greater than .05 for multiple months, and all fire types surpass the .001 level for at least one month. It is believed that some teleconnections may also lead to fire conditions. This study found that ENSO and AMO both had intelligible correlation patterns; while the other tested teleconnections' correlations did not have intelligible patterns at this point in our analysis of the data. All teleconnections were found to have at least one month that surpassed the .05 significance level for at least one of the fire types.

The northern and western ranger districts seem to be more fire prone; this is observed for both fire types. The percent of the area burned analysis most clearly shows this. Southern districts have a large number of fires, but they are smaller on average than the fires of the other areas.

Conclusions

The fire regime of the region seems to be tied to PDSI with the most highly significant correlations occurring during and soon before the fire season of the fire type being observed. There does not seem to be a need for a wet period before drought as there is in drier climates; there is plenty of fuels to burn not matter the recent climatic conditions.

The fire regime seems to be related to teleconnections as all have at least one month with a significant correlation to anthropogenic fires area burned; the question that will need to be answered about most of the teleconnections analyzed is what causes the seemingly sporadic changes in the correlations. There is a significant chance that low ENSO values during the late spring of the current year lead to more area being burned by anthropogenic fires. Negative correlations are found during the whole period for anthropogenic fires; this means that there is a higher chance of anthropogenic fires when ENSO values are low (La Nina conditions). The correlations for lightning fires’ area burned to ENSO are not as strong ranging from .20 to -.20 which is not strong enough to believe that they affect the fire regime significantly.

AMO had an intelligible correlation pattern and became somewhat strongly correlated during the previous year's spring and summer. The fact that AMO is such a long term teleconnection makes it interesting that the correlation to fire changes as much as it does through a 24 month period. It is the only analyzed teleconnection that reaches the .01 significance level which it does during the previous year's May and August for anthropogenic fires area burned. From the data it can be concluded that if there are high AMO values during the summer, there is a significant chance of increased area burned during the coming year.

Further analysis will have to be undertaken in order to form conclusions about the other teleconnections with seemingly sporadic correlation patterns, especially because the correlation values are significant in some cases. A possible way to further analyze the teleconnections would be to consider multiple teleconnections in tandem which has been successfully done in other studies on fire-teleconnection relationships.

Spatial patterns were observed at the National Forest ranger district level. Some of the more apparent patterns are: (1) that northern and western areas burn more thoroughly, (2) fires in the northern areas tend to be larger, (3) the Grandfather Ranger District (the northeast ranger district of the study area) seems to be prone to a large number of fires which tend to be large and (4) fires in the Great Smokey Mountain National Park tend to be few and large.

Pattern 1 is probably the result of drier, more continental conditions in the northern areas of the study caused by being further from the tropical moisture of the Gulf of Mexico and the mountains preventing moisture from penetrating further inland for the western areas of the study. Pattern 2 is probably the result of drier, more continental conditions allowing fire to spread more quickly. Pattern 3 may be the result of more lightning; this pattern needs to be further investigated. Pattern 4 is may be the result of differing fire management techniques in a national park than in a national forest.

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